PRODUCTION CONTRACTS AND PRODUCTIVITY IN THE U.S. HOG SECTOR

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This article measures the impact of contracting on partial and total factor productivity and the production technology of U.S. hog operations. A sample selection model accounts for the fact that unobservable variables may be correlated with both the operators' decision to contract and farm productivity. Results indicate that the use of production contracts is associated with a substantial increase in factor productivity, and represents a technological improvement over independent production. Results also identify determinants of farmers' decisions to contract and other factors influencing farm productivity.

Key words: production contracts, productivity, sample selection, technological difference.

The rapid increase in the use of production contracts is a notable feature of the structural change taking place in the US hog industry. Between 1992 and 1998, the portion of feeder pig-to-finish hog operations using production contracts increased from 11% to 34%, while the share of output produced under contract increased from 22% to 63% (McBride, McBride and Key). Production contracts offer several potential advantages over independent production that could explain their growing prevalence. Contracts may serve to lower transaction costs associated with search, negotiation, and transfer; reduce asymmetric information between growers and processors about product quality; improve coordination of product delivery; and lower income risk for growers. In addition, contracting may raise farm productivity by improving the quality of managerial inputs, by speeding the transfer of technical information to growers, or by facilitating growers' access to credit, thereby permitting the adoption of newer, more efficient technologies. In this article, we focus on identifying and measuring the farm-level productivity gains, if any, that can be attributed to contracting.

The recent growth in contracting does not necessarily imply that contracts are associated with higher farm productivity. The increase in the use of contracts may have been propelled by other benefits from contracting (such as lower grower income risk) that offset negative on-farm productivity effects. The use of contracts could potentially lower on-farm productivity if they reduce incentives for growers to work efficiently or to invest fully in specific productive assets. In addition, because contracts often take the form of share contracts, they do not fully reward grower effort, and farmers for whom high effort yields high return may choose not to contract.

Understanding the link between contracts and farm productivity is crucial to an analysis of the distributive and efficiency implications of the recent structural changes in the hog industry, and of policies to regulate contracting. The rapid growth in contracting has led to efforts at various levels of government to regulate contract production, both indirectly through corporate farming laws and zoning, and directly through legislation such as the "Producer Protection Act" (Boehlje et al.). These regulations may have significant social welfare costs or benefits depending in part on how contracting impacts hog farm productivity.

To measure the effect of contracting on farm productivity we must control for differences between farmers who choose to contract and those that do not. For example, contractees may be more credit-constrained, more risk-averse, may value autonomy less, or have less managerial or entrepreneurial ability—characteristics that could be correlated with farm productivity. Unfortunately, many factors correlated with both contracting and

productivity are unobservable. When this is the case, simply regressing productivity on exogenous factors and a contracting indicator will result in biased parameters. For example, if "management ability" is unobservable and positively correlated with contracting and productivity then the simple regression overestimates the impact of contracting on productivity. The problem is one of self-selection—farmers who choose to contract would have had relatively high productivity (because they have good management ability) whether or not they contracted.

We use a sample selection model to account for the fact that many of the determinants of both whether a farmer contracts and farm productivity are unobservable. In the sample selection model, two equations are estimated simultaneously: (*a*) a probit equation explaining the decision whether or not to contract, and (*b*) an equation explaining productivity, which includes a contracting dummy among the explanatory variables. The empirical model corrects for possible sample selection bias by accounting for the joint distribution of the disturbances. In the full-information maximum likelihood approach, the likelihood of observing a particular level of productivity depends explicitly on the likelihood that the farmer contracts.

Using the selection model, we use two approaches to measure differences in farm productivity between contract and independent operations: (*a*) differences in partial and total factor productivity, and (*b*) technological difference. Both approaches use information from the 1998 USDA Agricultural Resource Management Survey of feeder pig-to-finish hog operations. Empirical results identify the determinants of hog farmers' decisions to contract and also identify the factors that influence productivity. Results also shed light on the long-run implications of contracting for the scale of production.

In the next section, we review the literature examining the reasons why farmers and processors (or integrators) choose to contract. This past research provides insights into how contracting could impact farm productivity, which informs the empirical approach.

Contracting and Productivity

Under the terms of a typical production contract to finish hogs, the contractor provides feed, feeder pigs, veterinary care, managerial assistance, and marketing services.[1] Growers are paid a fee for raising the animals. The fee may have an incentive structure based on animal weight gain, death loss, or feed productivity. The feed and other inputs supplied by the contractor represent over 80% of the total costs of production (McBride and Key). Because contractors supply such a large share of the production costs, contracts drastically reduce the amount of production credit needed by growers. In addition, because a contract reduces price risk, a contract may make it easier for some farmers to obtain financing for setting up or expanding hog production (Boehlje and Ray). Indeed, Kliebenstein and Lawrence note that in a survey asking growers why they entered contractual arrangements, lack of capital was the second most frequently cited reason (after risk reduction). Contracting could, therefore, serve to relieve a binding credit constraint for some growers freeing them to invest or apply inputs at a more efficient level. On the other hand, because hog production involves large investments in specific assets, contracting may make growers vulnerable to changes in contract terms. If greater investment in specific assets reduces the bargaining power of contractees *vis-à-vis* the contractor, contractees may draw back from socially optimal levels of investment resulting in lower productivity (Shelanski and Klein).

Costs associated with measuring hog quality may result in asymmetric information between growers and purchasers of hogs that can affect productivity. If there is asymmetric information about product quality, then farmers have less incentive to invest in raising quality because they cannot be fully compensated for this investment by the purchaser (Hennessy). Production contracts that specify the genetic characteristics of the hogs reduce uncertainty about quality. Hence, these contracts can reduce measurement costs associated with asymmetric information and may encourage investment in quality (Martinez, Smith, and Zering).

Asymmetric information about the level of effort applied by growers may also have

implications for productivity. Hog contractors may seek to reduce moral hazard by using a share contract (Sheldon). Under a share contract growers receive less reward for their effort than they would under independent production. Consequently, share contracts, while reducing risk, may also result in lower grower effort.[2] Contractors may also have asymmetric information about the ability of potential contractees, which could create an adverse selection problem for the contractor. Rhodes notes that "in the Cornbelt their (commercial feed companies and packers) efforts to contract hog production largely subsided within a few years. The better producers were seldom interested in the quasi-employee status that did not provide access to the profits of the good years of the hog cycle." On the other hand, Knoeber views the growers' provision of productive assets (e.g., growing facilities) as a signal of agent ability under asymmetric information. Hence, the capital requirement may act as a screening device resulting in the self-selection of contractees with high ability.

Risk sharing is one of the mostly widely cited reasons for contracting. Hog contracts lower price risks for growers because contract fees usually do not depend on input or hog prices (Johnson and Foster, Martin, Kliebenstein and Lawrence). While reducing risk, contracts also reduce farmer autonomy (Gillespie and Eidman). Preferences for risk or autonomy may correlate with factors such as entrepreneurial ability and management skills that affect productivity.

Empirical Model

To measure the impact of participating in a production contract on farm productivity we use a treatment effects sample selection model (Greene, p. 714). The model assumes a joint normal distribution between the errors of the selection equation (contract/no contract) and the treatment equation (the measure of productivity). As discussed in the introduction, this approach accounts for the fact that unobservable variables may be correlated with both the operators' decision to contract and farm productivity, allowing for an unbiased estimate of the impact of contracting on productivity. The treatment effects approach is used

here rather than an instrumental variables approach because there are too few variables available with which to instrument the contracting dummy variable.

Let the latent variable C_i^* equal the net benefits to a grower from contracting compared to independent production and marketing:

$$(1) \qquad C_i^* = \mathbf{Z}_i \gamma + u_i$$

where

$$C_i = 1 \qquad \text{if} \qquad C_i^* > 0, 0 \text{ otherwise}$$

where $\mathbf{Z}_i$ is a vector of operator, farm, and regional characteristics. If the latent variable is positive then the dummy variable indicating contracting C_i equals one, and equals zero otherwise. We are interested in measuring the impact of a production contract on a measure of farm performance y_i:

$$(2) \qquad y_i = \mathbf{X}_i \beta + C_i \delta + \varepsilon_i$$

where $\mathbf{X}_i$ is a vector of operator, farm and regional characteristics.

We cannot simply estimate (2) because the decision to contract may be determined by unobservable variables (management ability, regional characteristics, etc.) that may also affect performance. If this is the case, the error terms in (1) and (2) will be correlated, leading to biased estimates of δ. To elaborate, suppose the errors have a joint normal distribution with the following form:

$$\begin{bmatrix} u \\ \varepsilon \end{bmatrix} \sim N \left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \rho \\ \rho & \sigma^2 \end{bmatrix} \right).$$

It follows that the expected performance of contractees is given:

$$(3) \qquad \begin{aligned} E[y_i \mid C_i = 1] &= \mathbf{X}_i \beta + \delta + E[\varepsilon_i \mid C_i = 1] \\ &= \mathbf{X}_i \beta + \delta + \rho \sigma \lambda_i \end{aligned}$$

where $\lambda_i = \frac{\phi(\alpha_i)}{1 - \Phi(\alpha_i)}$ is the inverse Mills ratio and $\alpha_i = -\mathbf{Z}_i \gamma$.[3] Equation (3) implies that omitting λ_i in an ordinary least squares regression of (2) would lead to omitted variable bias in estimates of β and δ. To derive unbiased parameter estimates we can use a two-stage approach starting with a probit estimation of (1). In the second stage, estimates of γ_i are used to compute the inverse Mills ratio, which is included as an additional term in an OLS estimation of (2). This two-stage Heckman procedure is

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[2] However, incentive schemes that link grower fees to feed or reproductive efficiency, rate of weight gain, performance relative to other growers, etc. can significantly mitigate incentive problems resulting from share contracts (e.g., Knoeber).

[3] This follows because $E[\varepsilon_i \mid C_i = 1] = E[\varepsilon_i \mid C_i^* > 0] = E[\varepsilon_i \mid u_i > -\mathbf{Z}_i \gamma]$, and from the definition of the expectation of a truncated bivariate normal distribution (e.g, Greene, p. 685–87).

consistent, albeit not efficient. Efficient maximum likelihood parameter estimates can be obtained by maximizing

$$
\begin{aligned}
L(\gamma, \beta, \sigma, \rho) \\
= \prod_{C_i=0} \int_{-\infty}^{0} \int_{-\infty}^{\infty} f\left(C_i^*, y_i; \gamma, \beta, \sigma, \rho\right) dy\, dC^* \\
\cdot \prod_{C_i=1} \int_{0}^{\infty} \int_{-\infty}^{\infty} f\left(C_i^*, y_i; \gamma, \beta, \sigma, \rho\right) dy\, dC^*
\end{aligned}
$$

where $f(C_i^*, y_i; \gamma, \beta, \sigma, \rho)$ is the joint normal density function, which is a function of the parameters. In practice, the negative of the log of the likelihood function is minimized using the estimates from the Heckman procedure as starting values.[4]

Measures of Productivity

Using the treatment effects model, we use two approaches to measure the impact of contracting on productivity: (*a*) partial and total factor productivity, and (*b*) technical progress. For the first approach, y_i in (2) is a measure of factor productivity. For the second approach, y_i is hog output and $X_i\beta$ is a production function. If contracting is allowed to interact with all the exogenous variables, (2) becomes

$$
(2') \qquad y_i = \mathbf{X}_i\beta + C_i\mathbf{X}_i\delta + \varepsilon_i
$$

where δ is now a vector of parameters associated with the interaction terms.

Using a translog production function, (2′) takes the form

$$
\begin{aligned}
\log q_i &= \beta_0 + \sum_k \beta_k \log x_{ik} \\
&\quad + \frac{1}{2}\sum_k \sum_l \beta_{kl} \log x_{ik} \log x_{il} \\
&\quad + \delta_0 C_i + \sum_k \delta_k C_i \log x_{ik} \\
&\quad + \frac{1}{2}\sum_k \sum_l \delta_{kl} C_i \log x_{ik} \log x_{il} \\
&\quad + \sum_m \alpha_m z_{im} + \varepsilon_i
\end{aligned}
$$

where $\beta_{ij} = \beta_{ji}$, x_{ik} are the four inputs (feed, labor, capital, other), z_{im} are exogenous shifters, and C_i is a dummy variable equal to one if operation *i* uses a production contract,

and equal to zero otherwise. Interacting the contract dummy with all the inputs allows the impact of contracting to vary nonlinearly with the scale of production. We use the estimated production function to test whether growers can produce more under contract compared to independent production, holding inputs constant.

Data

Data used are from two sources: operator and farm-level data are from the 1998 USDA Agricultural Resource Management Survey of the hog sector, and county-level characteristics are from the 1997 US Agricultural Census. Because of the broad differences in production techniques among various types of hog operations, we limit the study to feeder pig-to-finish hog operations.[5] This group of producers has experienced rapid growth in contracting and accounted for about a third of total hog farms and production in 1998.

Table 1 reports the results of tests of equal means between contract and independent operations for the variables used in the estimations.[6] The table highlights several clear differences between the two groups. On average, contractees are younger and have much less experience in the hog business. Contractees are also more likely to have their major occupation be something other than farming or ranch work. Contract operations are much larger—producing on average over three times as much pork as independent operations. Among the five geographical regions in which the sample is divided, contracting is significantly more common than independent production only in the East. Independent production is more common in all the other regions except the North, where there is no significant difference between the modes of production.

County-level measures of income and hog farm concentration are included as measures of the availability, and consequently the net benefits of contracting to growers. Contractors choose to locate and expand production in regions where they can operate most profitably—where the opportunity costs to hog

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[4] See documentation for LIMDEP 7.0 for details about the optimization algorithm.

[5] Feeder pig-to-finish operations are defined as those on which feeder pigs (30–80 pounds) are purchased/placed, finished, and later sold/removed for slaughter at a weight of approximately 200–260 pounds.

[6] In computing the difference of means, parameters, and significance tests in all the regressions in the article, the survey data were weighted to account for sample design.

Table 1. Tests of Equality of Means for Independent and Contract Operations

Variables	Mean Independent Operations	Mean Contract Operations	t-statistic	Prob. > |t|
Operator Characteristics				
Age (years)	50.6	47.0	3.78	0.000
Education (years)	13.0	12.9	0.06	0.953
Major occupation is off-farm[a]	0.14	0.23	−2.41	0.016
Years in hog business	24.1	14.8	9.03	0.000
Farm Characteristics				
Total farm assets ($100,000)[b]	7.62	8.70	−1.25	0.211
Scale Class 1: Hog production (cwt.) < 1000[a]	0.408	0.065	9.68	0.000
Scale Class 2: 1000 ≤ Hog production (cwt.) < 2000[a]	0.224	0.098	3.79	0.000
Scale Class 3: 2000 ≤ Hog production (cwt.) < 5000[a]	0.196	0.221	−0.67	0.505
Scale Class 4: 5000 ≤ Hog production (cwt.) < 10000[a]	0.130	0.254	−3.47	0.001
Scale Class 5: 10 000 ≤ Hog production (cwt.)[a]	0.041	0.361	−9.40	0.000
Regional Characteristics				
Northern state (MI, MN, SD, WI)[a]	0.194	0.232	−1.02	0.306
Eastern state (NC, SC, VA)[a]	0.014	0.205	−6.94	0.000
Southern state (AL, AR, GA, MO, KY, TN)[a]	0.085	0.032	2.50	0.013
Western state (CO, KS, OK, UT, NE)[a]	0.159	0.067	3.20	0.001
Central Midwestern state (IL, IN, IA, OH)[a]	0.548	0.463	3.17	0.064
County average net cash return per farm ($1000)	34.86	46.54	−4.64	0.000
County average swine sales per farm ($1000)	23.63	70.73	−6.8	0.000
Output and Inputs[c]				
Hog production (cwt.)	2678	10672	−9.67	0.000
Feed (cwt.)	9874	26163	−7.84	0.000
Labor (hours)	1226	1608	−3.40	0.001
Capital ($)	16791	56837	−9.14	0.000
Other Inputs ($)	7928	24473	−6.29	0.000
Productivity[d]				
Feed productivity (cwt. hog/cwt. feed) × 10^{-1}	2.69	4.34	−11.13	0.000
Labor productivity (cwt. hog/labor hour)	1.96	6.54	−13.50	0.000
Capital productivity (cwt. hog/$) × 10^{-2}	14.59	18.23	−5.24	0.000
Other inputs productivity (cwt. hog/$) × 10^{-2}	50.01	65.84	−4.16	0.000
Total factor productivity (cwt. hog/$) × 10^{-2}	2.21	3.36	−12.52	0.000
Number of observations	233	244		

Notes: All data are from the 1998 USDA-ERS ARMS except county-level variables, which are from the 1997 US Agricultural Census. Means are weighted to account for survey design. Prob. > \|t\| is the two-tailed significance probability under the null hypothesis of equal means.
[a] Dummy variable equal to 1 if statement is true or located in region, 0 otherwise.
[b] Total farm assets include both hog and nonhog components of the operation.
[c] Hog production is measured as hundredweight of hogs sold or removed under contract less hundredweight of hogs purchased or placed under contract plus hundredweight of inventory change. Labor includes own and hired labor; Capital is the capital replacement value; Other inputs include veterinary, bedding, marketing, custom work, energy, repair.
[d] Factor productivity is hog production (see note c) per unit of input. Total factor productivity is the inverse unit cost.

farming are low, or where there is a high density of hog producers, which lowers transaction costs. While most hog farmers may have some opportunity to contract, the net benefits of contracting will be higher where the availability of contracting is greater. As shown in the table, contract operations are more likely to be located in counties with a high net cash returns per farm, and in counties with a greater volume of hog production. We did not expect counties with higher net returns to farming to be correlated with contracting, and as we find

in our regressions discussed in the next section, once we control for operator, farm, and other regional characteristics, the positive relationship between county average farm revenue and contracting actually becomes negative.

Inputs definitions and mean values for contract and noncontract operations are presented in table 1. Since contractors provide some of the inputs used in the production of hogs, care was taken to account for inputs supplied by *both* the contractee and the contractor. Fortunately, the survey explicitly

asked respondents for both the contractors' and contractees' contribution for all the components in the "other inputs" category, including medicine and marketing. On the other hand, for some capital items it was not possible to determine the contractor's contribution. For this reason, we excluded feed grinders and mixers, feed wagons, feed trucks, and stock trailers from the capital variable—as these items are associated with services often provided by a contractor. The labor variable included all paid and unpaid labor used on the hog operation. For paid labor, the survey asks for the contributions from the operator and partners, landlord, and contractor—so we are able to compute the total quantity. However, for unpaid labor we only know the contribution from the grower. Consequently, if the contractor provides *unpaid* labor towards production activities performed by an independent operation (such as feed milling or hauling pigs) this would not be included in the labor variable, and labor productivity would appear higher for contract operations. However, because labor represents such a small share of the total cost (about 8%) it is unlikely that this would significantly alter the results of the total factor productivity or production function estimates.

The comparison of means presented in table 1 indicates that contract producers are on average much more productive than independent producers: they produce much more per unit of feed, labor, and capital, and have higher total factor productivity. The relationship between contracting and productivity holds even if we control for operator, farm, and regional characteristics. Table 2 reports the results of linear regressions of the five measures of productivity on contracting and exogenous characteristics. As shown in the table, contracting is significantly positively correlated with factor productivity. As mentioned above, unobservable factors may be correlated with the decision to contract, so the least squares estimates of the impact of contracting on factor productivity may be biased. Correcting for this selection bias is the concern of the next section.

Results

The Contract Decision

Table 3 lists the results of the first stage probit explaining the decision to contract versus produce independently. The results of the probit are used to compute the inverse Mills ra-

tio used in the two-stage procedure. Estimates from the two-stage procedure are used as starting values in the likelihood estimation. The model is significant and correctly predicts 83% of operators' choices. Most variables had signs consistent with the differences in means discussed in the last section. Estimation results indicate that for an average operation, an increase in education or years of experience in the hog business lowers the probability that the farmer will contract, while having a primary occupation off-farm, raises the likelihood of contracting. It is possible that more experienced, better educated, full-time farmers are less likely to accept a contract because these farmers could earn relatively more producing independently than could less educated, less experienced, part-time farmers.

An operation being located in an Eastern state positively increases the likelihood of contracting, so did being located in a Northern state or not being located in a Southern state (all relative to the omitted region: Central Midwestern). As expected, being located in a county with more hog production increases the likelihood of contracting—likely because this lowered transactions costs for the contractor.[7] Also as expected, being in a county with a higher average net return to farming lowers the probability that a farmer contracts—a higher income means a higher reservation wage for the contractor.

As shown in table 3, the scale of production has a strong positive correlation with the likelihood of contracting. Controlling for individual, regional, and farm-level characteristics, being in a farm-scale category other than the smallest increases the likelihood of contracting, and the increase in the size of the coefficients with the increase in size group indicates that the probability of contracting increases with scale.

Factor Productivity

In order to estimate the impact of contracting on partial and total factor productivity, we

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[7] Higher hog production per farm at the county level implies a greater concentration of hog production units and/or larger-scale production units. A denser concentration of producers implies lower transportation costs associated with input delivery and product pick-up. Larger production units imply lower fixed costs associated with transportation, screening and search for potential contractees, negotiation of contracts, and monitoring behavior for breech of contract.

Table 2. Least Squares Regression Estimates: Partial and Total Factor Productivity

	Feed		Labor		Capital		Other Inputs		TFP	
	Coeff	P-value	Coeff	P-value	Coeff	P-value	Coeff	P-value	Coeff	P-value
Constant	3.536	0.000	3.158	0.006	8.080	0.058	52.598	0.006	2.294	0.000
Age	0.003	0.757	−0.028	0.044	0.053	0.250	0.270	0.240	−0.008	0.040
Education	−0.128	0.003	−0.090	0.200	−0.037	0.888	−2.079	0.077	−0.041	0.073
Off-farm occupation	0.619	0.002	−0.243	0.440	0.268	0.835	−8.582	0.103	0.117	0.290
Years in hog business	0.009	0.245	0.006	0.629	−0.020	0.679	0.132	0.519	0.007	0.095
Total farm assets	−0.002	0.854	0.020	0.147	−0.025	0.428	−0.112	0.624	0.003	0.340
Scale class 2	0.342	0.112	0.318	0.361	3.554	0.035	10.708	0.066	0.438	0.002
Scale class 3	0.380	0.095	0.974	0.008	5.441	0.002	10.903	0.076	0.808	0.000
Scale class 4	0.996	0.000	2.756	0.000	8.458	0.000	2.062	0.740	1.375	0.000
Scale class 5	1.450	0.000	6.471	0.000	9.903	0.000	7.210	0.357	1.561	0.000
Southern state	0.762	0.008	0.572	0.217	6.258	0.000	22.891	0.003	0.385	0.003
Western state	−0.039	0.856	0.639	0.065	3.735	0.021	21.236	0.000	0.066	0.635
Northern state	−0.029	0.873	0.331	0.265	1.633	0.229	−3.004	0.544	0.251	0.031
Eastern state	−0.180	0.549	0.664	0.171	0.619	0.670	−22.750	0.005	−0.389	0.002
Contract	1.205	0.000	2.036	0.000	2.148	0.095	25.065	0.000	0.769	0.000
Adjusted R²	0.269		0.602		0.182		0.114		0.485	
Mean of dep. Var.	3.737		5.195		18.819		50.404		2.895	
Input cost share	0.663		0.081		0.173		0.083		n.a.	
Increase in productivity due to contracting (%)	32.25		39.19		11.40		49.73		26.56	

Notes: Dependent variables in the Factor Productivity equations are feed, labor, capital, other inputs, and total factor productivity. The P-value is the value for a two-tailed test of the hypothesis that the coefficient equals zero. Number of Observations: 477. Input cost share is the share in total costs of the input associated with the factor productivity variable. The "increase in dependent variable due to contracting" is the estimated percentage increase in factor productivity attributed to contracting, for an average operation.

Table 3. Binomial Probit Maximum Likelihood Estimates: Contract Decision

Variable	Coefficient	Standard Error	t-ratio	P-value
Constant	0.975	0.775	1.259	0.208
Age (years)	0.003	0.009	0.304	0.761
Education (years)	−0.163	0.050	−3.258	0.001
Major occupation is off-farm	0.631	0.217	2.911	0.004
Years in hog business	−0.024	0.008	−2.870	0.004
Total farm assets ($100,000)	−0.006	0.009	−0.614	0.539
Scale Class 2 ($1000 \leq$ cwt. < 2000)	1.040	0.261	3.978	0.000
Scale Class 3 ($2000 \leq$ cwt. < 5000)	1.507	0.267	5.651	0.000
Scale Class 4 ($5000 \leq$ cwt. < 10000)	1.729	0.259	6.665	0.000
Scale Class 5 ($10000 \leq$ cwt.)	2.635	0.325	8.116	0.000
Southern state (AL, AR, GA, MO, KY, TN)	−0.843	0.373	−2.258	0.024
Western state (CO, KS, OK, UT, NE)	−0.309	0.267	−1.159	0.246
Northern state (MI, MN, SD, WI)	0.297	0.185	1.606	0.108
Eastern state (NC, SC, VA)	0.774	0.430	1.801	0.072
Co. average net return per farm ($1000)	−0.015	0.006	−2.544	0.011
Co. average swine sales per farm ($1000)	0.006	0.003	2.150	0.032
Log likelihood	−195.288			
McFadden R^2	0.409			

Notes: Dependent variable: uses a production contract (1,0); number of observations: 477; chi-squared: 270.433, degrees of freedom: 15, significance level: 0.000. The model correctly predicts the contract decision for 202 of the 234 independent producers, and for 196 of the 244 contract producers.

assume factor productivity can be approximated with a linear function of the explanatory variables.[8] There is no theoretical reason to expect either county hog production or county average farm income to affect on-farm productivity, so these are omitted from the estimation. The maximum likelihood estimates of the sample selection model are presented in table 4. The estimated coefficients in the top half of the table correspond to the selection equation, and are consistent with the results of the probit model discussed in the previous subsection.

The coefficients in the bottom half of table 4 correspond to the factor productivity equations. In terms of operator characteristics, age appears to lower labor and total factor productivity, perhaps because some older farmers may be semi-retired, or because older farmers are more likely to use aging capital equipment which they do not plan to replace due to their impending retirement. Education reduces the probability that a farmer will contract, and has a significant positive correlation with capital productivity. Surprisingly, education also has a significant negative correlation with feed and total factor productiv-

ity. An alternative model specification that includes quadratic terms sheds some light on this result.[9] When this model is estimated, the education coefficient is positive and significant and the education-squared coefficient is negative and significant in both the feed and total factor productivity equations. Hence, the net impact of education appears to be positive at low levels of education and negative at high levels. A further analysis of the data reveals that the highest educated producers (with sixteen years of education or more) have smaller-scale operations, are more likely to work off-farm, and have greater wealth than do average producers. This relatively affluent, well-educated group may be more likely to view farming as a "hobby" or secondary activity, with resultant lower factor productivity.

Having off-farm work as a primary occupation increases the likelihood of contracting and has a positive effect on feed productivity. It is possible that having an off-farm primary occupation implies that the farmer is more likely to purchase feed rather than produce

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[8] As discussed later in the section, alternative models are estimated to assess the robustness of the results to different model specifications.

[9] Model 2 uses a quadratic functional form that includes education and education squared in the productivity equations—it is discussed in more detail later in this section. Results of model 2 for the education and education^2 variables in the feed and TFP equations are as follows: education = 1.192, P-value = 0.043; education^2 = −0.050, P-value = 0.016 for feed productivity; education = 0.712, P-value = 0.009; education^2 = −0.028, P-value = 0.005 for total factor productivity.

Table 4. Selection Model Maximum Likelihood Estimates: Partial and Total Factor Productivity

	Feed		Labor		Capital		Other Inputs		TFP	
	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value	Coeff.	P-value
Selection Equation										
Constant	1.256	0.164	1.239	0.189	1.159	0.130	0.954	0.309	1.127	0.199
Age	−0.001	0.932	−0.003	0.756	0.001	0.911	0.003	0.780	0.003	0.796
Education	−0.177	0.003	−0.162	0.010	−0.174	0.001	−0.162	0.011	−0.172	0.006
Off-farm occupation	0.631	0.013	0.607	0.013	0.774	0.001	0.625	0.015	0.595	0.017
Years in hog business	−0.022	0.029	−0.021	0.038	−0.022	0.010	−0.025	0.013	−0.024	0.010
Total farm assets	−0.005	0.706	−0.004	0.798	−0.003	0.790	−0.005	0.718	−0.005	0.682
Scale class 2	0.990	0.003	0.956	0.004	0.966	0.001	1.006	0.002	0.945	0.004
Scale class 3	1.518	0.000	1.249	0.000	1.583	0.000	1.476	0.000	1.450	0.000
Scale class 4	1.793	0.000	1.789	0.000	1.714	0.000	1.717	0.000	1.790	0.000
Scale class 5	2.638	0.000	2.647	0.000	2.193	0.000	2.608	0.000	2.585	0.000
Southern state	−0.664	0.160	−0.706	0.154	−0.854	0.016	−0.853	0.073	−0.713	0.121
Western state	−0.395	0.307	−0.321	0.346	−0.318	0.296	−0.308	0.403	−0.313	0.389
Northern state	0.303	0.109	0.213	0.306	0.527	0.002	0.281	0.168	0.337	0.079
Eastern state	0.710	0.277	0.867	0.159	0.675	0.087	0.723	0.261	0.738	0.220
Co. farm net return	−0.015	0.055	−0.013	0.077	−0.016	0.009	−0.014	0.103	−0.015	0.045
Co. swine sales per farm	0.007	0.149	0.006	0.162	0.007	0.028	0.006	0.186	0.006	0.180
Factor Productivity										
Constant	3.707	0.000	3.584	0.003	6.935	0.090	54.456	0.021	2.738	0.000
Age	0.002	0.862	−0.030	0.023	0.031	0.534	0.261	0.335	−0.008	0.098
Education	−0.133	0.007	−0.104	0.174	0.488	0.065	−2.130	0.107	−0.092	0.000
Off-farm occupation	0.627	0.004	−0.203	0.568	−0.885	0.487	−8.451	0.246	0.158	0.159
Years in hog business	0.010	0.260	0.007	0.589	−0.050	0.312	0.136	0.577	0.013	0.001
Total farm assets	0.000	0.997	0.024	0.034	0.026	0.656	−0.096	0.745	0.002	0.693
Scale class 2	0.414	0.078	0.496	0.547	−0.654	0.680	11.482	0.120	0.591	0.000
Scale class 3	0.448	0.154	1.141	0.111	2.393	0.099	11.656	0.138	0.997	0.000
Scale class 4	1.056	0.000	2.915	0.000	4.451	0.004	2.699	0.755	1.482	0.000
Scale class 5	1.480	0.000	6.566	0.000	4.261	0.023	7.465	0.456	2.043	0.000
Southern state	0.699	0.008	0.409	0.444	7.319	0.000	22.103	0.003	0.591	0.000
Western state	−0.083	0.786	0.551	0.212	3.334	0.034	20.820	0.001	0.462	0.000
Northern state	−0.013	0.942	0.379	0.330	2.268	0.040	−2.821	0.665	0.316	0.001
Eastern state	−0.358	0.320	0.258	0.514	−1.676	0.386	−24.693	0.070	−0.520	0.006
Contract	1.328	0.000	2.308	0.000	3.054	0.020	26.402	0.000	0.661	0.000
Sigma	1.460	0.000	2.376	0.000	8.619	0.000	39.111	0.000	0.765	0.000
Rho	−0.230	0.112	−0.328	0.006	−0.519	0.000	−0.093	0.552	−0.269	0.051
Log likelihood	−1047.4		−1274.4		−1909.1		−2620.2		−737.2	
R^2	0.324		0.493		0.142		0.257		0.593	

Notes: Table presents maximum likelihood parameter estimates for sample selection model: dependent variable in the "Selection Equation" is contract (1,0); dependent variables in the "Factor Productivity" equations are feed, labor, capital, other inputs, and total factor productivity. The P-value is the value for a two-tailed test of the hypothesis that the coefficient equals zero. Number of observations = 477. The R^2 statistic corresponds to the "Factor Productivity" equations.

it on-farm. Purchased feed may have superior quality compared to "own-produced" feed resulting in higher feed productivity (contract operations are also less likely to use "own-produced" feed which may partly explain why contracting is associated with higher feed productivity). Finally, the number of years in the hog business has two confounding effects on total factor productivity: an extra year in business *increases* total factor productivity directly, however an extra year in business also reduces the likelihood of contracting, which *decreases* total factor productivity indirectly. The net marginal impact of an extra year in the business on total factor productivity is computed to be only 0.00921.

In terms of farm and regional characteristics, more farm assets are associated with higher labor productivity. This may result because larger farms have more financial liquidity, which allows an optimal application of purchased inputs—raising labor productivity. Most of the indicators of scale of production are significant determinants of productivity, except in the case of "other inputs." In addition, the value of the coefficients increases with the scale implying a positive relationship between scale and factor productivity. Surprisingly, in terms of a regional effect (controlling for all the other factors) being located in a Southern state is correlated with the largest increase in productivity (compared to the Central-Midwest) for every measure of factor productivity except labor. This does not imply that the South has the highest productivity (it does not) rather it suggests that there are unobservable regional factors (e.g., climate, regional technological differences, unobserved factor quality, or price differences) that are correlated with partial or total factor productivity.

Contracting is significant in all factor productivity equations. Note that the estimated correlation between the errors of the two equations ρ is significant and negative in the labor, capital and total factor productivity equation (and almost significant at the 10% level in the feed equation). This result indicates that we would have underestimated the impact of contracting on labor, capital, and total factor productivity had we not taken into account the selectivity bias (the bias resulting from the fact that contractees are not randomly selected from the population of hog producers, but are self-selected). Table 5 lists the estimated coefficients, standard errors, P-values, and the estimated impact of contracting on factor productivity for four model specifications. The

Table 5. Impact of Contracting on Factor Productivity under Various Model Specifications

Factor	Coefficient	Coefficient/ Standard Error	P-value	Log L	Percentage Increase
Model 1: All scale classes, linear functional form					
Feed	1.328	4.786	0.000	−1047.41	35.53
Labor	2.308	6.985	0.000	−1274.35	44.44
Capital	3.054	2.331	0.020	−1909.10	16.23
Other inputs	26.402	4.119	0.000	−2620.21	52.38
TFP	0.661	6.352	0.000	−737.17	22.81
Model 2: All scale classes, quadratic functional form					
Feed	1.478	5.153	0.000	−1016.88	39.56
Labor	2.772	8.046	0.000	−1213.58	53.35
Capital	3.426	2.495	0.013	−1836.68	18.20
Other inputs	29.882	4.195	0.000	−2591.65	59.28
TFP	0.833	6.845	0.000	−730.25	28.77
Model 3: Three middle scale classes, linear functional form					
Feed	1.604	3.716	0.000	−459.19	45.35
Labor	1.956	5.092	0.000	−533.24	54.95
Capital	2.362	1.375	0.169	−818.33	14.28
Other inputs	24.976	2.607	0.009	−1167.87	48.01
TFP	0.605	3.347	0.001	−329.58	20.89

Notes: The "Coefficient" refers to the estimated parameter for the "Contract" dummy variable in equation (2); "Percentage Increase" is the estimated percentage increase in factor productivity attributed to contracting, for an average operation. Model 1: All scale classes, using scale class dummy variables and linear functional form for selection equation (same model as presented in table 4). Model 2: All scale classes with scale and scale-squared rather than scale class dummies in selection equation, plus additional quadratic terms in selection equation. Model 3: same as Model 1, except restricted to scale class 2–4. See text for details about models.

results of the model described above are shown in the table under "model 1." For an average hog farm, contracting raises feed, labor, capital, other inputs, and total factor productivity by 35.5%, 44.4%, 16.2%, 52.3%, and 22.8%, respectively.

It is possible that the linear functional form used is not sufficiently flexible to control for scale or regional effects. A linear approximation may result in biased parameters if omitted higher-order terms that should have been included in the regression were omitted. We can generalize the linear specification (model 1) by including: (*a*) scale and scale-squared as regressors rather than scale dummies, (*b*) quadratic terms for all continuous variables, and (*c*) interaction terms between scale and all other variables in the linear model. The results of this generalized model are presented under "model 2" in table 5.

A third model specification can be used to address the fact that the smallest scale category is comprised primarily of independent producers, while the largest category primarily of contract operations. Model 3 is a reestimation of model 1 using only the subset of producers in the three middle-sized scale categories. The results of all three models produce similar estimates of the impact of contracting on factor productivity.[10]

Technology

The second approach to measuring the impact of contracting on productivity involves estimating a production function, taking into account the selection process. Table 6 reports the result of the maximum likelihood estimation where for convenience input levels have been normalized by dividing by their mean value. The top of the first column presents the estimates of the bivariate selection equation, which again are similar to those obtained in the probit equation (table 3). The remaining coefficients correspond to the production function.

A likelihood ratio test is used to test the joint null hypothesis of no technical difference between contractees and independent producers:

$$H_0 : \delta_0 = \delta_k = \delta_{kl} = \delta_m = 0 \quad \text{for all} \quad k, l, m.$$

The likelihood ratio test statistic has a value of 91.77, and the P-value associated with the chi-square distribution with fifteen restrictions is less than 0.001. Hence, we reject that null hypothesis that contractees and independent producers use the same technology.

A discrete index of technical change can be constructed using the estimated production function

$$\tau = \frac{\hat{q}(\hat{\beta}, \hat{\delta}, \hat{\alpha}, \bar{\mathbf{x}}, \bar{\mathbf{z}}, C = 1)}{\hat{q}(\hat{\beta}, \hat{\alpha}, \bar{\mathbf{x}}, \bar{\mathbf{z}}, C = 0)}$$

where $\hat{q}$ is the estimated production function evaluated at the input levels and with the exogenous characteristics of an average operation. The index is simply the ratio of what can be produced by contracting relative to what can be produced by independent production with the same input bundle. Our estimate of the index indicates that contracting raises productivity for an average producer by 20.2%.

Conclusions

Accounting for exogenous grower, operation, and regional characteristics, and for sample selection bias we find that contract operations are substantially more productive than independent operations. In addition, contracting appears to represent a technological improvement over independent production resulting in about 20% more output for an average farm, holding inputs constant. The magnitudes of the productivity gains, which can be attributed to contracting are striking, and are consistently large under various model specifications.

The increases in productivity that result from contracting may be due to a transfer of "know how" from integrators to growers, which may be particularly important given the relative lack of hog experience of the contractees. This information transfer may involve knowledge about feed mixtures or feed timing that results in higher feed productivity and lower labor costs. In addition, it is possible that the goods and services provided by the contractor—such as veterinary care, feed, and especially the genetic quality of the animals—may be superior to that available to an independent producer, resulting in healthier animals and greater weight gain. Consequently, part of the estimated gains in productivity may

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[10] Measures of collinearity of the regressors *X* and *Z*, tests of the assumption of normality of the errors, and results of alternative model specifications that relax the assumption of exogeneity of scale in the productivity selection equations were also consistent with the empirical approach and results. Please contact the authors for additional documentation.

Table 6.   Selection Model Maximum Likelihood Estimates: Production Function

	Coefficient	P-value		Coefficient	P-value
Selection Equation					
Constant	1.195	0.211	Scale class 4	1.691	0.000
Age	0.000	0.992	Scale class 5	2.565	0.000
Education	−0.165	0.008	Southern state	−0.765	0.095
Major occup. off-farm	0.603	0.033	Western state	−0.383	0.373
Years in hog business	−0.025	0.020	Northern state	0.288	0.169
Total farm assets	−0.005	0.729	Eastern state	0.722	0.291
Scale class 2	0.974	0.005	Co. farm net return	−0.015	0.052
Scale class 3	1.428	0.000	Co. swine sales per farm	0.007	0.153
Production Function					
Constant	−0.864	0.000	$C * \ln x4 \ln x4$	−0.062	0.463
$\ln x1$	0.619	0.000	$C * \ln x1 \ln x2$	0.291	0.165
$\ln x2$	0.173	0.044	$C * \ln x1 \ln x3$	−0.184	0.562
$\ln x3$	0.366	0.000	$C * \ln x1 \ln x4$	0.334	0.045
$\ln x4$	0.066	0.374	$C * \ln x2 \ln x3$	−0.513	0.036
$\ln x1 \ln x1$	−0.004	0.911	$C * \ln x2 \ln x4$	−0.014	0.932
$\ln x2 \ln x2$	−0.120	0.028	$C * \ln x3 \ln x4$	−0.235	0.201
$\ln x3 \ln x3$	0.010	0.829	Age	0.002	0.432
$\ln x4 \ln x4$	−0.017	0.686	Education	−0.012	0.338
$\ln x1 \ln x2$	−0.020	0.786	Major occupation off-farm	0.008	0.889
$\ln x1 \ln x3$	−0.003	0.961	Years in hog business	0.001	0.766
$\ln x1 \ln x4$	0.040	0.531	Total farm assets	0.002	0.291
$\ln x2 \ln x3$	0.116	0.125	Southern state	0.223	0.005
$\ln x2 \ln x4$	0.062	0.432	Western state	0.170	0.007
$\ln x3 \ln x4$	−0.036	0.662	Northern state	−0.055	0.271
C (Contract)	0.509	0.000	Eastern state	0.013	0.914
$C * \ln x1$	−0.095	0.509			
$C * \ln x2$	−0.078	0.578	Sigma	0.356	0.000
$C * \ln x3$	−0.092	0.541	Rho	−0.211	0.321
$C * \ln x4$	0.089	0.399			
$C * \ln x1 \ln x1$	−0.158	0.265	Log likelihood	−376.44	
$C * \ln x2 \ln x2$	0.108	0.374	R^2	0.956	
$C * \ln x3 \ln x3$	0.327	0.144			

Note: Table presents maximum likelihood parameter estimates for sample selection model. Dependent variable in the selection equation is Contract (1,0); Dependent variable in the Production Function equation is log of production ($\times 10^{-4}$). The P-value is the value for a two-tailed test of the hypothesis that the coefficient equals zero. In the regression all inputs ($x1$ = feed, $x2$ = labor, $x3$ = capital, $x4$ = other) have been normalized relative to the sample mean. Number of observations = 477. The R^2 statistic corresponds to the "Production Function" equation.

be the result of our inability to account for quality differences in the inputs.[11]

Some of the productivity gains from contracting might be explained by differences in access to capital—if contract growers are able to obtain more financing because they face less risk then they could more easily adopt newer and more productive capital equipment than independent growers. However, as shown in table 1, contract growers do not have significantly more total farm assets (even though they have much larger hog operations), and a further analysis (not reported here) reveals

no significant difference between contractees and independent producers in terms of their debt-to-asset ratio. Hence, the evidence fails to suggest that contracting improved growers' access to external funds. On the other hand, total farm assets, as defined, do not include hogs, feed, and other assets provided by the contractor. This probably explains why much larger (in terms of production) contracting farms do not have significantly more assets than smaller independent farms: for the same investment, contract growers can produce more because they do not have to purchase animals, feed, and the equipment provided by contractors. It follows that with the same financial resources as independent growers, contract growers could obtain technology that is more productive and/or achieve a larger more efficient scale of production.

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[11] To some extent, the differences in the quality of inputs were controlled for in the TFP equation, where price was used to weight the inputs. This may explain why contracting was estimated to have a smaller impact on TFP than most of the other partial factor productivity measures.

The magnitude of the estimated productivity gains attributable to contracting suggests that this was likely an important factor in the recent growth in contracting in the hog industry. In addition, contracting may have played a role in the recent increase in the average scale of production. Because contract operations are larger operations, on average, it will be larger operations that enjoy the productivity gains from contracting. Consequently, in practice, contracting may serve to enhance the competitive position of larger producers vis-a-vis smaller producers.

The higher level of farm productivity associated with contracting implies that policies to regulate contracting have economic costs. However, it is possible that negative producer welfare effects (loss of autonomy) or upstream and downstream *costs* to contracting (increased transactions costs) could reduce or even reverse the potential on-farm efficiency gains from contracting. Hence, it is not possible to conclude from this study what the overall impact of policies to restrict contracting would be on producers or society. In addition, while the results suggest that contracting raises on-farm productivity, it is important to stress that this analysis did not consider nonmarket costs of production such as odor or water pollution. Future work might examine whether and how contracting is associated with particular manure management practices or other environmental impacts.

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